Processing of Energetic Materials at Thiokol's 19mm Twin Screw Extrusion Facility

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Abstract

A 19mm, 25 l/d twin screw extrusion (TSE) facility has been built and used for processing energetic materials. The extruder is equipped with four independent temperature control zones, segmented screws, a jacketed die block capable of accepting various dies, and a remote control capability. The facility has been equipped with loss in weight (LIW) feed systems for raw material handling and has vacuum capability. Data monitoring capabilities include melt temperature and pressure, torque, screw speed, and temperatures in all of the control zones. A variety of post processing equipment has also been designed and fabricated for use in manufacturing various different extrudate geometries. A summary of extruder design considerations, facility issues, and lessons learned in operating the extruder during the processing of various energetic material formulations will be discussed in this paper.

Introduction

Thiokol Corporation has been involved in the development of twin screw extrusion technology since the early 1980's. Beginning in 1982, a company funded IR&D program was initiated to evaluate process requirements for the production of LOVA gun propellant. This project marked the start of over $3M in R&D and capital expenditures made by Thiokol to support continuous processing of energetic materials in a 58mm twin screw extruder (TSE) at the Longhorn Army Ammunition Plant (LAAP). As a result of the initial program, twin screw extrusion was found to offer significant technical advantages over batch processing of energetic materials in the areas of safety, environmental issues, product quality, cost reduction, and processing flexibility.

The Thiokol LAAP extrusion facility utilized a Werner & Pfleiderer (W&P) ZSK-58EH split barrel twin screw extruder for the processing of energetic materials. The design of this machine evolved as a result of extensive evaluation of early modular barrel twin screw extruders at NSWC Indian Head, Massachusetts Institute of Technology, NSWC White Oak, ICT Fraunhofer Institute, and Thiokol LAAP. Detailed hazards analysis specific to energetic materials production were conducted on these modular barrel extruders which identified significant potential safety hazards with existing extruder designs. Results of these safety analyses and extensive safety testing including full scale ignition tests of a modular barrel extruder loaded with energetic material led to specific design requirements for an extruder optimized for production of energetic materials. A joint design effort between LAAP and W&P was initiated which resulted in the split barrel extruder design designated ZSK-58EH with specific features and safety enhancements to allow processing of energetic materials. A ZSK-58EH TSE was fabricated and installed at LAAP during the mid 1980's[1]. This extrusion facility began processing energetic materials in 1989[2,3].

Thiokol LAAP demonstrated the use of 58mm twin screw extrusion technology during the execution of several different energetic material programs during the late 1980's and early 1990's[4,5]. Formulations produced with this processing technology included propellants, explosives, and pyrotechnics. Not only were the basic mixing and extrusion issues related to the production of each type of formulation quantified, but valuable system design information was gathered and improvements were made to the ancillary equipment and processes that support the overall manufacturing technology. Methods suitable for feeding both liquid and solid raw materials, for addition and removal of solvents to in-process material, and for waste minimization were also developed. Table 1 below lists the types, formulations, and quantities of the energetic materials that have been produced using the 58mm TSE.

Table 1. Energetic Materials Produced at LAAP using 58mm TSE Technology.

Material	Ingredients	Quantity, lbs
Rocket Propellant	AP, Al, HTPB, IPDI	500
PAX-4 High Explosive	CAB, HMX , DEGDN, TEGDN	1000
PAX-2A High Explosive	CAB, HMX, BDNPA/F	1000
M39 LOVA Gun Propellant	CAB, Ethyl Centralite, Ethyl Acetate, NC, RDX	200
M43 LOVA Gun Propellant	CAB, Ethyl Centralite, BDNPA/F, NC, RDX	200
TPE LOVA Gun Propellant	LRG-999, RDX, NC	150

In order to consolidate processing capability, the 58-mm TSE facility installed at LAAP was relocated to the Thiokol Wasatch Plant located in Utah during 1997. All of the extrusion processing equipment previously located at LAAP has been transferred to the Utah plant and is currently being thoroughly refurbished and reinstalled. Inert energetic material processing operations began at the new facility in June of 1998, and live processing of energetic materials are currently being conducted to support contract delivery requirements.

Background

Extrusion processing capability was enhanced at Thiokol Corporation in 1996 with installation of 19mm B&P Process Equipment TSE at Thiokol Wasatch Science and Engineering (S&E) Laboratories. Capitalizing on the design efforts completed by LAAP, the 19mm TSE was selected based on its similar split barrel design, similar processing capabilities, and lower throughput rate. This machine was 25 l/d in length, had segmented screws and multiple temperature control zones. The lower throughput rate of this machine, nominally 5-10 lbs/hr, when compared to the 58mm TSE, nominally 75-250 lbs/hr, allowed for the development and production of smaller quantities of new energetic material formulations. Working in conjunction with B&P technical representatives, Thiokol S &E personnel converted the 19mm TSE from a plastics processing machine to one capable of safely producing highly energetic materials. Safety enhancements and modifications included design of a remotely located control system, elimination of metal to metal contact points, and a complete replacement of the extruder drive motor system to allow operation in an explosion proof manner.

The facility was equipped with two solid feed systems; both manufactured by Brabender Technologies. One of the feed systems was a 20mm twin screw gravimetric loss-in-weight feeder. This system was microprocessor controlled, and used to feed live molding powders to the extruder. The second feed system was a single screw volumetric feeder used to deliver an inert molding powder to the extruder. The inert molding powder utilized the same thermoplastic elastomer (TPE) binder formulation as the live formulation, the same level of solid loading by mass, and the same solid material particle size distribution. The inert material was delivered to the extruder at the same mass flow rate as the live material and was used during start-up of the process to center the screws. The inert material was also used during shutdown to purge the extruder of live material prior to opening the equipment for cleaning and maintenance.

This extrusion system was successfully used to process 280 lbs of live TPE based gun propellant. The material that was produced had high-density values, nominally 99 % of the theoretical maximum density of the formulation, and exceptionally smooth surface finishes. Ballistic reproducibility of the material was also found to be excellent.

However, despite the initial success in extruding energetic materials at this facility, an incident occurred during the processing of additional TPE based gun propellant. In-process material was ignited in the discharge end of the extruder, and the resulting fire propagated along the length of the extruder screws and into the feed chute used to deliver the molding powder to the extruder. Since the feed chute was a solid stainless steel tube, the fire easily continued to propagate to the molding powder remaining in the hopper.

This molding powder rapidly deflagrated, causing significant damage to both the feed system and the rest of the facility. The incident investigation led to several recommendations for improving the system safety of original extruder installation. These recommendations included use of a more elaborate data collection system that displayed trending of key processing variables in real time, installation of an IR thermocouple at the die discharge to independently monitor extrudate temperature, and development of a system that allowed the feeder to be isolated from the extrusion process.

19mm Facility at M-241

As a result of the processing incident involving gun propellant, Thiokol was presented with the opportunity to build a new small-scale extrusion facility at another more remote location. The new location at building M-241 was chosen due to its remote location from the rest of the plant and the overall design of the building and control bunker. The M-241 building was much larger than the previous facility while the control bunker was an entirely separate building designed as an earthen structure capable of withstanding an energetic event. The M-241 building was also tall enough to allow the installation of a mezzanine that would be used to house feed systems. An additional benefit to choosing this facility was the presence of all utilities, vacuum equipment, and climate control equipment including humidity control.

Based on previous experience with the initial 19mm TSE facility, a decision was made to procure an identical, new 19mm machine from B&P, as well as a new solid gravimetric loss in weight feed system from Brabender Technologie. As with the first facility, several safety enhancements had to be added to the extruder to allow processing of energetic materials. These enhancements included the addition of an Allen Bradley based control system complete with real time trending capability, elimination of metal to metal contact points, and a complete replacement of the extruder drive motor system to allow operation in an explosion proof manner. Additional equipment that was installed in the facility includes a second solid gravimetric feed system, two liquid gravimetric feed systems, and a volumetric single screw feed system. Brabender Technologie also supplied these additional feeders.

Unique in the installation of this equipment was the development and testing of a solid feeder isolation mechanism[6]. Tests conducted at Thiokol showed that using such a mechanism to isolate energetic material feed equipment and feed streams from the extrusion processing equipment would greatly increase overall system safety. The system installed in the facility is shown diagrammatically in Figure1 below.

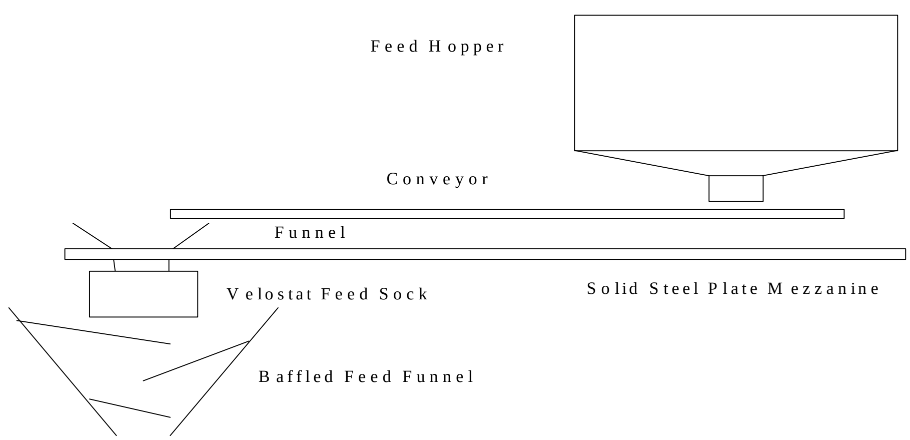
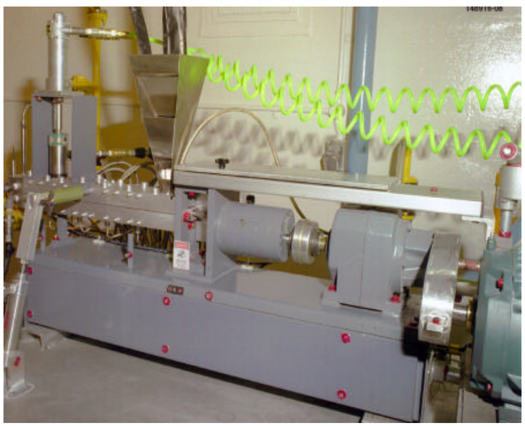


Figure 1: Diagram of Feeder Isolation Mechanism.

The isolation system uses a conveyor located on the mezzanine to deliver raw material from the feeder to a funnel located approximately 2 feet from the feeder discharge on the floor of the mezzanine. Raw materials pass through this funnel into a Velostat sock that discharges into a baffled feed funnel. The baffled funnel has three interior baffles that do not allow the raw material to travel in a straight path downward into the extruder. Additionally, these baffles were designed to direct any flame from an extruder fire outward into the processing bay, while minimizing the amount of flame that travels upward through the Velostat sock. This feeder isolation system was tested using live material, an old twin screw extruder, and a full scale engineering prototype of the baffled funnel, Velostat sock, mezzanine funnel, and conveyor. In the final test, energetic material within the extruder was initiated using an electric match and the resulting flame from the decomposition of the material did not reach the raw material on the conveyor belt.

Changes were also made to the fire detection system in the M-241 facility. A total of 5 IR sensing detectors were used in the new deluge system to detect the occurrence of an anomalous event. These five sensors were positioned to allow maximum coverage of the extruder and redundant coverage of the feed systems. The completed facility is depicted in the photographs that comprise Figure 2.



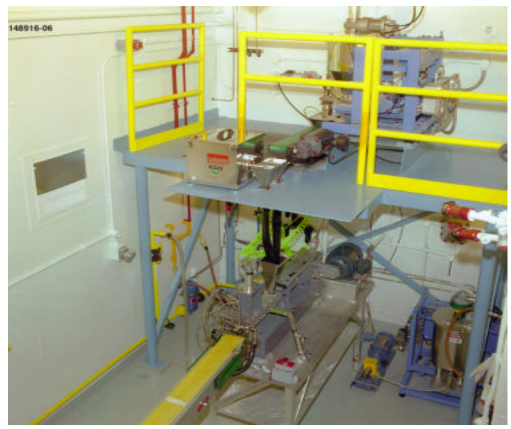


Figure 2: Photographs of M-241 19-mm Twin Screw Extrusion Facility

In addition to installing several safety enhancements in the M-214 facility, Thiokol's participation in the Army's TIME program[7] allowed the installation of a fiber optic computer network which allows remote monitoring of processing operations at M-241. The system utilizes two computers within the control room to send both real time processing and video data to other locations on the network. Currently, the additional nodes on the network are located at the U.S. Army ARDEC facility in Picatinny, New Jersey, and at the Stevens Institute of Technology in Hoboken, New Jersey.

Processing Results

The M-241 facility became operational in March of 1998. Since that time, approximately 1,500 pounds of energetic material have been extruded in this facility during the completion of 60 extrusion runs. Energetic formulations that have been processed range from TPE gun propellants to solvent-based explosives. The longest extrusion run required 60 hours to complete and produced 240 lbs of TPE gun propellant material. All runs were interrupted on an hourly basis to collect extrudate and to refill feed hoppers.

During the course of an extrusion run, several processing parameters are monitored, recorded, and presented in a trend format. Monitored parameters include screw speed, screw torque, raw material feed rates, die pressure, melt temperature, barrel zone temperatures, IR thermocouple measured temperature, and vacuum level. Data are displayed in a real time format on the computer system used to control the process, while a separate computer is used to generate trend plots of the process variables and to record all processing data. Use of a two-computer system allows for real time temporal comparisons of both instantaneous processing data and trends with past results. This system has been advantageous in the design and optimization of different extrusion processing configurations. Typical processing data from a run that produced a solvent-based explosive are shown in Figure 3.

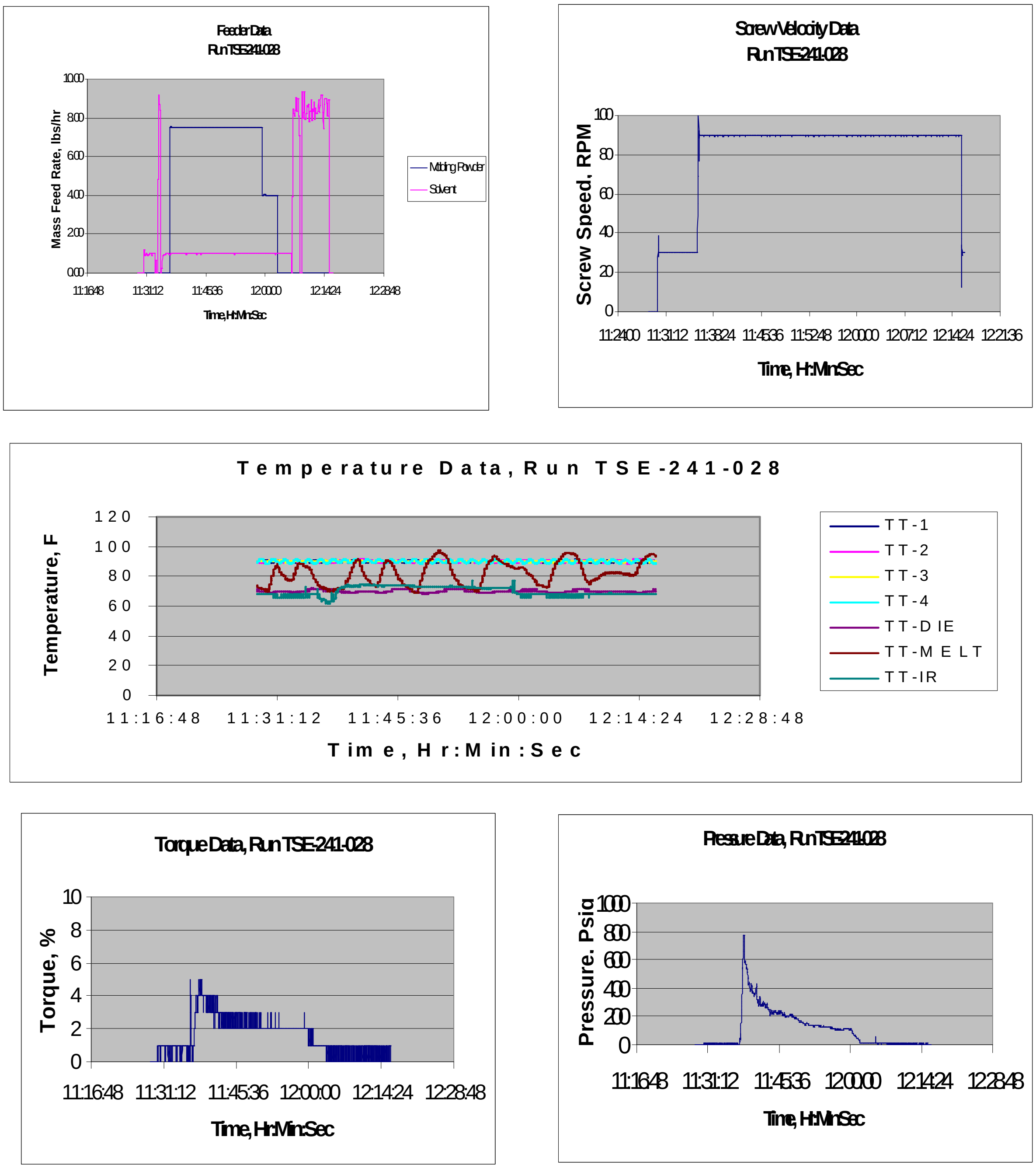


Figure 3: Data from Processing Run TSE-241-028

Extrudate geometries that have been produced include 0.5-inch diameter, 7 perforation strands, solid strands with a width of approximately 0.8 inches and thickness of 0.2 inches, and various cylindrical strands ranging in diameter from 0.1 inches to 0.5 inches. Two different methods have been successfully employed to produce different extrudate geometries. One method involves the use of a die bolted to the exit plane of a jacketed die block attached to the end of the extruder. The second method involves incorporation of the die geometry within the die block. All extrudate dies were designed, manufactured, and tested by Thiokol personnel.

Conclusions

The 19mm TSE facility at Thiokol has been used to produce a large variety of energetic materials. Extrudates produced in this facility include explosives, gun propellants, and pyrotechnics. Based on this processing experience, the following conclusions can be drawn:

1.) The 19mm TSE can be configured to safety process energetic materials. The segmented screw design and multiple feed ports on this machine allow for a wide range of processing options. Vacuum application may be used to achieve high-density products.

2.) Employing a mechanism to separate the feed systems from the extruder can significantly increase safety of processing operations. In this facility, feeder isolation is accomplished using a conveyor belt, a Velostat feed sock, and a baffled feed funnel.

3.) Using a computer control system that displays processing data in both a real time and a trend format can significantly increase processing capability and safety.

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5.) Dillehay, D.R., "Continuous Processing of Energetics on Twin Screw Extruders", Proceedings of the Life Cycle of Energetics, 1994.

6.) Rose, M.T., Haaland, A.C., Bradley, S.J., and Harper, M.R., "A Method of Isolating Energetic Material Feed Systems from Extrusion Processes", Manuscript in Preparation.

7.) U.S. Army Contract with Thiokol Corporation. Contract Number DAAA-21-94-D-003, Task 12.

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50 YEARS OF SOLID PROPULSION

Thiokol Propulsion

From Cordant Technologies

Outline

- **Overview and background**
  - Previous extrusion processing efforts at Thiokol
  - Initial 19mm TSE Facility
- **Installation of New Facility at M-241**
  - Feed System Isolation
  - Control System
  - Additional Process Monitoring
- **Processing Results**
  - Process Parameters
  - Extrudate Quality
- **Summary**

Overview & Background

Previous Extrusion Processing Efforts at Thiokol

- **Initial twin screw extruder (TSE) installed at Longhorn Army Ammunition Plant (LAAP)**
  - 58 mm diameter Werner & Pfleiderer extruder
  - Several liquid and solid feed systems
  - Development of post processing equipment and techniques
- **Extrusion facility was successfully used to process propellants, explosives, and pyrotechnics.**

Material	Ingredients	Quantity, lbs
Rocket Propellant	AP, Al, HTPB, IPDI	500
PAX-4 High Explosive	CAB, HMX , DEGDN, TEGDN	1000
PAX-2A High Explosive	CAB, HMX, BDNPA/F	1000
M39 LOVA Gun Propellant	CAB, Ethyl Centralite, Ethyl Acetate, NC, RDX	200
M43 LOVA Gun Propellant	CAB, Ethyl Centralite, BDNPA/F, NC, RDX	200
TPE LOVA Gun Propellant	LRG-999, RDX, NC	150

- **Facility moved from LAAP to Utah in 1997**

Overview & Background

Thiokol 58mm TSE located in Utah

- Facility is currently operational processing live materials

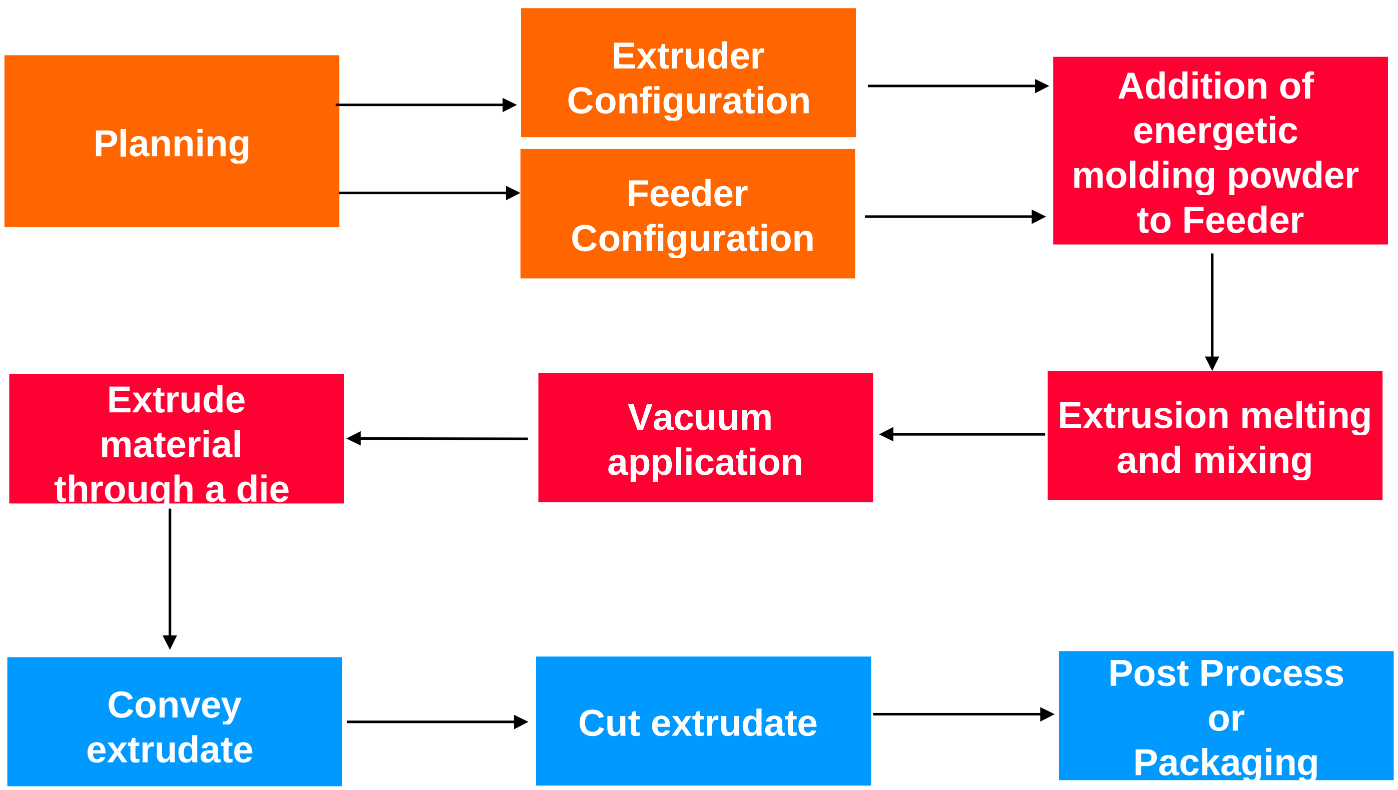
Overview and Background

Initial 19mm TSE Facility

- **Success at LAAP cultivated a desire to create small scale TSE facility in Utah**
- **Selected B&P 19mm TSE**
  - 25 l/d, segmented screw, split barrel design
  - 5-10 pounds/hour through put rate
  - Converted from plastics machine to energetic machine
    - Explosion proof electrical
    - Elimination of metal to metal contact points
    - Remotely located control system
- **Selected Brabender twin screw gravimetric feeder**
- **Successfully processed 280 pounds of TPE gun propellant**
- **Thiokol designed product collection equipment**

Overview & Background

Initial 19mm TSE Facility Process Flow



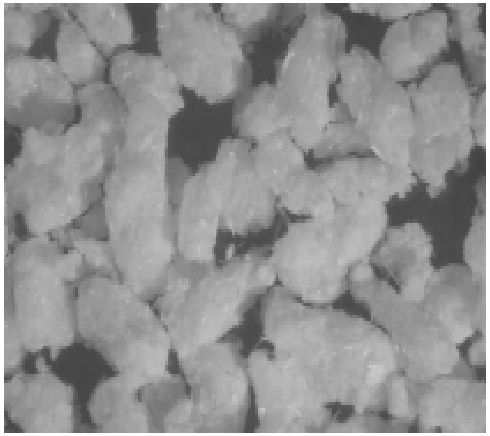
= Initial studies (Inert and Live)

= Extrusion operation

= post-extrusion operation

Overview & Background

Initial 19mm TSE Facility



Molding Powder For Twin Screw Extrusion Feedstock

M-56 19mm TSE

Solid Strand Gun Propellant Extrudate

Overview & Background

19mm TSE Processing Incident

- **Incident Description**
  - Occurred while processing TPE Gun Propellant
  - Ignition result of thermal decomposition due to overwork in discharge end of extruder
  - Fire propagated to forward end of extruder, spread up feed chute, and ignited remaining molding powder in feed hopper
- **Damage Assessment**
  - Feeder and hopper completely destroyed
  - Sustained minor damage to extruder
  - Significant damage to processing building
- **Provided opportunity to learn and build a better facility**

Overview & Background

19mm TSE Incident

- **Investigation results**
  - Improve data collection and control capability
  - Install better instrumentation on extruder
  - Isolate feeder from extrusion process
  - Isolate process from other areas of the plant
- **Incident was viewed as an opportunity**
  - Initial extrusion efforts were viewed as successful
  - Lessons learned could be applied to construction of a newer, more capable small scale facility
  - Investigation results could be applied to a wide range of energetic materials processes

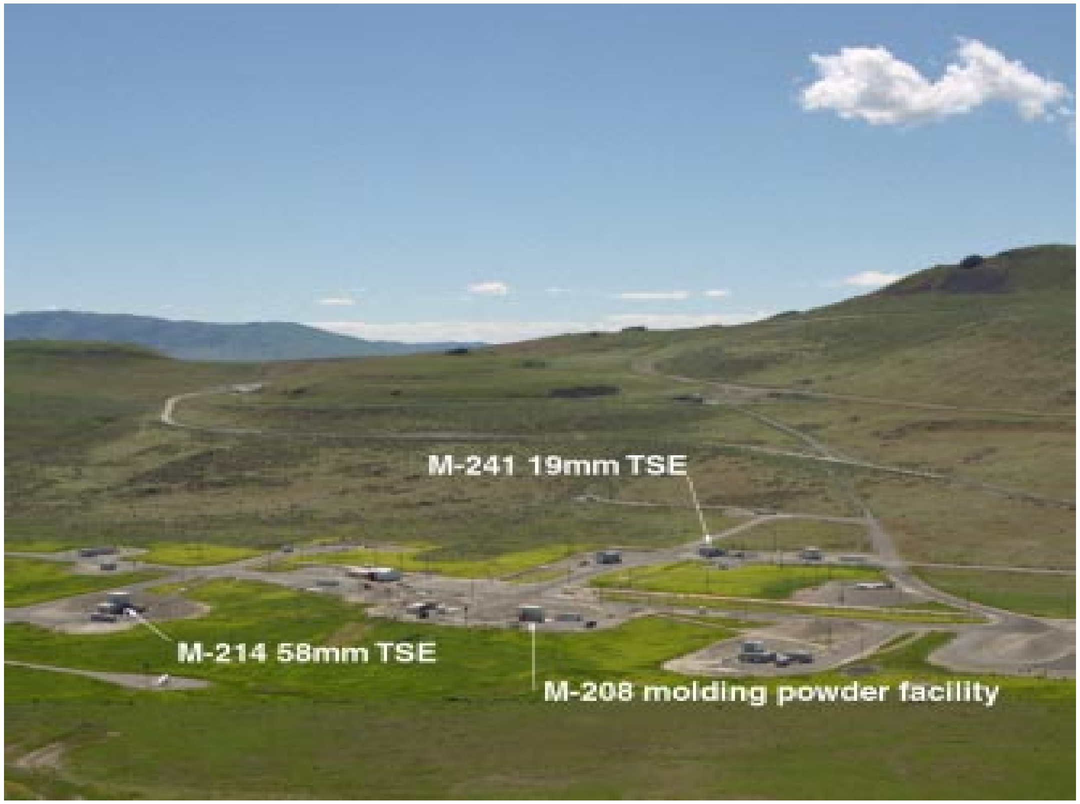
Extrusion Facility Installation

Facility Design Activities

- **Facility Design divided into four major areas**
  - Search for new location
    - More remote location
    - Dedicated, bunker style control room
  - Feed system isolation studies
    - Extruder fire would not propagate to feeder
    - System would allow fire detection and deluge operation
  - New control system design
    - Computer based
    - Real time trending capability
  - Improved process instrumentation
- **All activities were undertaken in a parallel manner**

Extrusion Facility Installation

Facility Design Activities - New Location

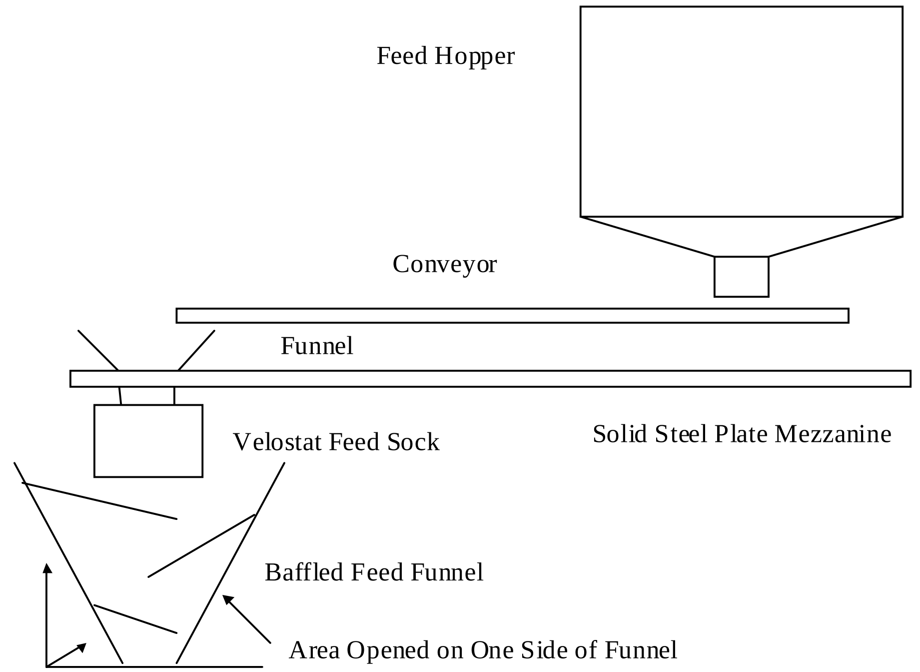


- M-241 selected due to remote location, dedicated control bunker

Extrusion Facility Installation

Feed System Isolation Studies

- **System design employed a conveyor, solid steel plate mezzanine, Velostat® feed sock, and baffled funnel. Thiokol has a patent pending on this approach.**



Extrusion Facility Installation

Feed System Isolation Studies

- **Complete system was tested using live materials**

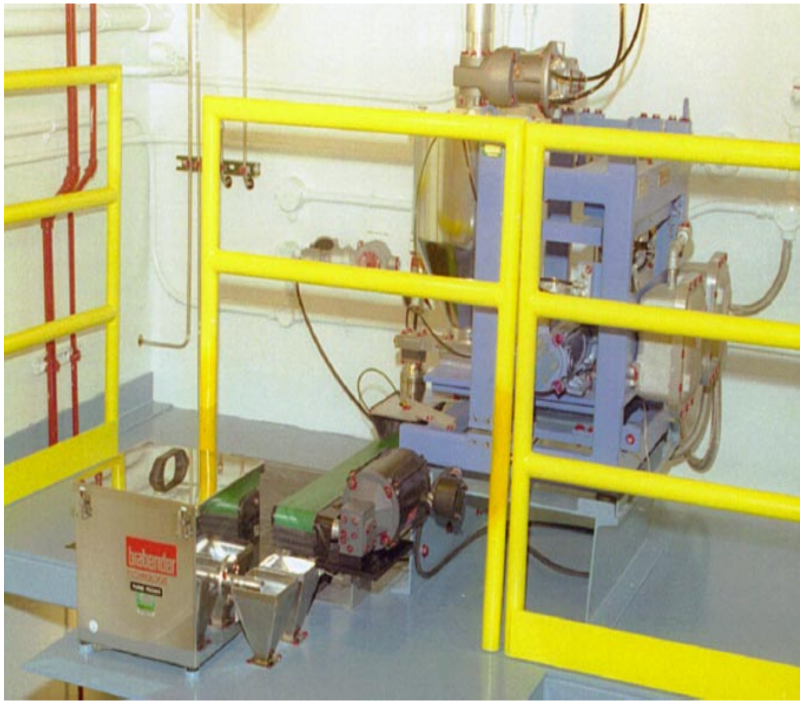
- **Fire did not propagate to feed hopper**

Extrusion Facility Installation

New Control System and Instrumentation

- **Computer based control and data acquisiton**
  - Allen Bradley hardware and software utilizing data highway
  - RSTrend for data acquisition and display of processing data trends
    - Temperatures and pressure
    - Extruder torque and screw speed
  - RSView for process control
    - Operation of all process equipment
    - Instantaneous display of set points and actual performance
- **Army TIME program installed real time network for data transfer**
- **Instrumentation was also improved**
  - Added IR thermocouple to independently measure extrudate temperatures
  - Direct coupled torque and rpm instrumentation to drive shaft

Extrusion Facility Installation

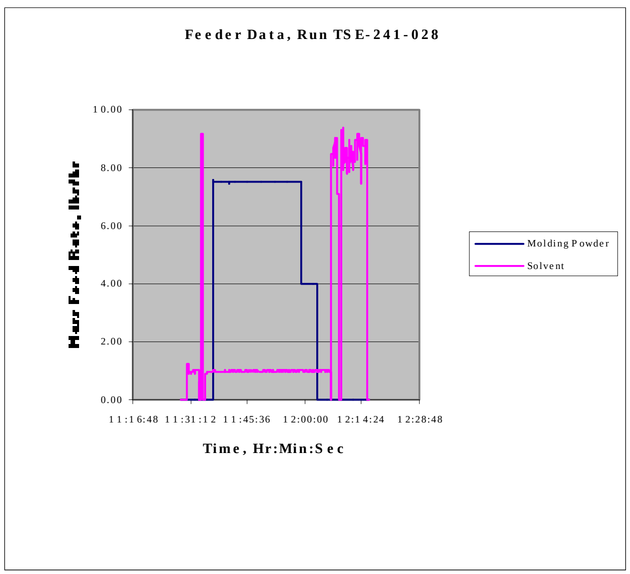


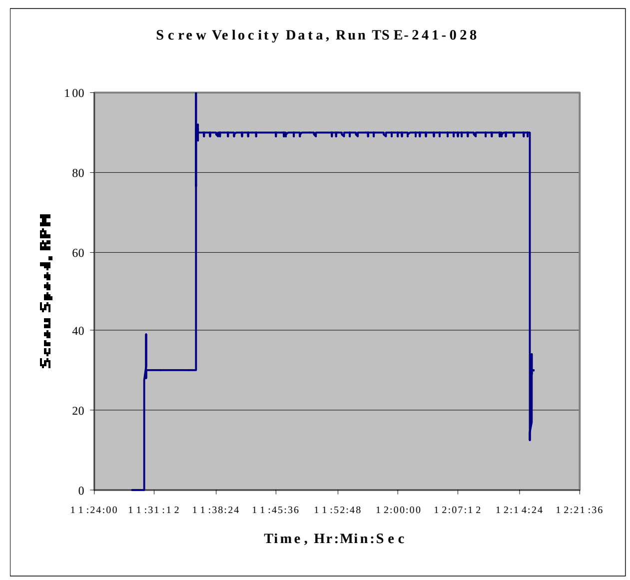
M-241 Facility was completed and operational in March,1998

M-241 Extrusion Facility Processing

Process Parameter Data

- **Facility has been used to complete over 60 runs of energetic material**
  - Longest run time is 64 hours
  - Approximately 1500 lbs of material total has been processed
- **Processing data is analyzed and stored**

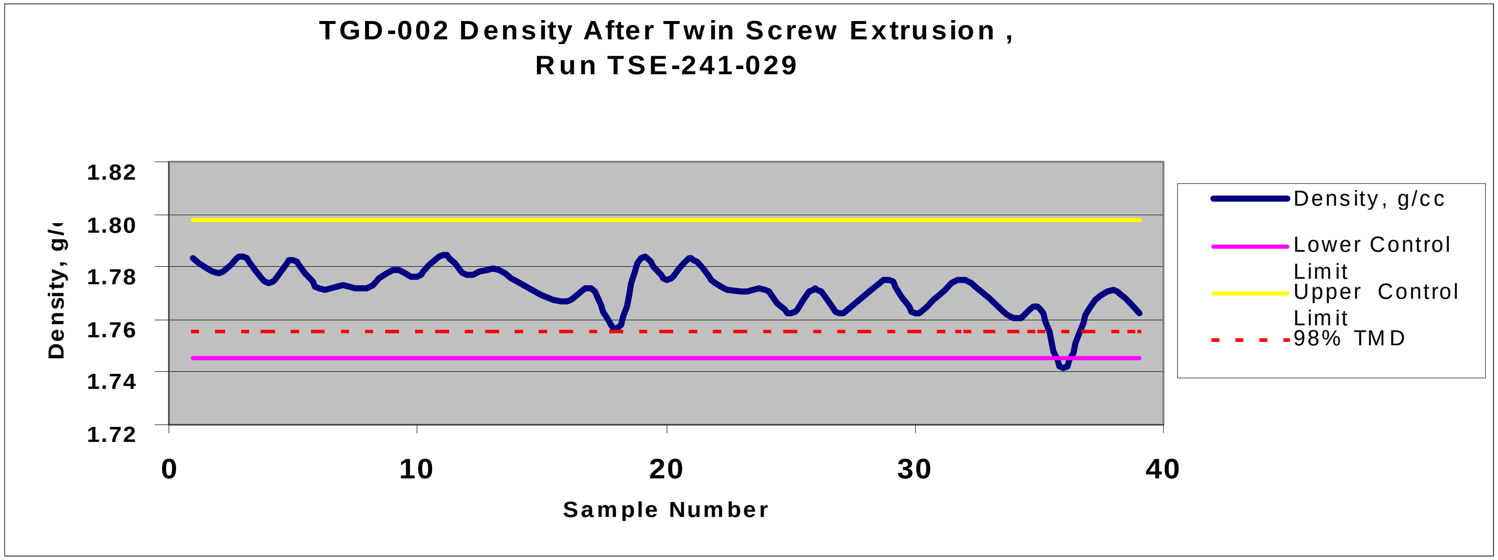




M-241 Extrusion Facility Processing

Extrudate Quality

- **Most commonly used measures of extrudate quality are density and surface finish**
  - Surface finish is a qualitative measurement, however poor surface finish can indicate low density
  - High density extrudate has been achieved with vacuum application during long run times



Summary

- **M-241 19mm TSE facility has successfully been used to process energetic materials**
  - Approximately 1500 pounds total
  - Longest run time was 64 hours
- **Facility design was improved through past experience**
  - LAAP 58mm TSE
  - M-56 19mm TSE
- **Facility capable of producing a wide range of energetic materials**
  - Gun propellants
  - Explosives
  - Pyrotechnics